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Skeletal Muscle Mass and Muscle Strength in Relation to Lower-Extremity Performance in Older Men and Women

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OBJECTIVE: Low muscle strength is associated with poorer physical function, but limited empirical evidence is available to prove the relationship between muscle mass and physical function. We tested the hypothesis that persons with lower muscle mass or muscle strength have poorer lower-extremity performance (LEP).

DESIGN: A cross-sectional, population-based study.

PARTICIPANTS: A cohort of 449 men and women aged 65 years and older living in Amsterdam and its surroundings participating in the second examination (1995–1996) of the Longitudinal Aging Study Amsterdam.

MEASUREMENTS: Leg skeletal muscle mass was measured using dual-energy X-ray absorptiometry (DXA). Grip strength was used as an indicator of muscle strength. Timed functional performance tests, including walking and repeated chair stands, were used to assess LEP.

RESULTS: After adjustment for body height and age, leg muscle mass was positively associated with LEP in men (regression coefficient 0.178 [95% confidence interval 0.013–0.343], $P = .035$). In women an inverse association was observed, which became positive after additional adjustment for body mass index (BMI) (0.202 [–0.001–0.405], $P = .052$). Grip strength was positively associated with LEP in men and women. After additional adjustment for behavioral, physiological, and psychological variables, the associations between leg muscle mass and LEP disappeared, whereas grip strength remained to be independently associated with LEP in men (0.079 [0.042–0.116], $P = .0001$), with a tendency in women (0.046 [–0.009–0.101], $P = .11$). Results were similar when quartiles of leg muscle mass or grip strength were used.

CONCLUSIONS: These results suggest that low muscle strength, but not low muscle mass, is associated with poor physical function in older men and women. However, prospective studies are needed to investigate the association between loss of muscle mass and physical function. *J Am Geriatr Soc* 48:381–386, 2000.

Key words: aged; cross-sectional studies; epidemiology; geriatric assessment; hand strength; human; leg physiology; skeletal muscle; walking

Muscle mass decreases with increasing age, even when body weight remains stable. Between the ages of 20 and 70 years, skeletal muscle mass in the arms and legs is estimated to decline by 11% in women and 15% in men.¹ This decline in muscle mass, which is often accompanied by a decline in muscle strength, is called sarcopenia and has been hypothesized to have functional consequences in old age.^{2–4} Previous studies have shown that lower muscle strength is associated with poorer physical function.^{5–8} However, limited empirical evidence has been published to support the relationship between muscle mass and physical function.^{9,10}

Recently, two studies have been published that tested the hypothesized relationship between low muscle mass and poor physical function in older men and women. Baumgartner et al.,⁹ using a validated anthropometric equation to predict skeletal muscle mass, observed that lower muscle mass was associated with more self-reported physical disability, this relationship being stronger in men than women. However, Visser et al.¹⁰ directly measured skeletal muscle mass using dual-energy X-ray absorptiometry (DXA) and found no association between total body muscle mass or leg muscle mass and self-reported disability for either men or women.

The inconsistency between the results of these studies can possibly be explained by differences in the methodology for assessing muscle mass, but also by limitations in the methodology for assessing physical function. Both studies were limited by their use of self-reported disability, which is a subjective measure of physical function influenced by depressive symptoms, perceived mastery, cognitive status, and gender.^{11–13} and consequently substantial misclassification may occur.¹⁴ Another method for assessing physical function is the use of timed functional performance measures.¹⁴ These measures offer an advantage over self-reported disability in that physical function can be objectively measured, even among those with no self-reported disability.^{14,15} Therefore, the use of timed functional performance measures rather than self-reported disability may help to clarify the potential association between muscle mass and physical function.

The present cross-sectional study was conducted among participants in the Longitudinal Aging Study Amsterdam (1995–1996) and investigated the associations of skeletal

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muscle mass and muscle strength with lower-extremity performance (LEP) as measured by timed functional performance tests in older men and women. Lower-extremity performance is predictive of subsequent falls, nursing home admission, and mortality,^{14,16,17} showing the importance of investigating the etiology of poor LEP. We tested the hypothesis that persons with lower leg muscle mass or grip strength have poorer LEP.

METHODS

Sample

The Longitudinal Aging Study Amsterdam cohort was originally recruited for the study "Living Arrangements and Social Networks of Older Adults" and included a stratified random sample of men and women, weighted according to expected mortality at midterm (after 5 years of follow-up) in six birth-year categories (1908–1912, 1913–1917, 1918–1922, 1923–1927, 1928–1932, and 1933–1937) obtained from the registries of 11 municipalities in three geographical areas in the west, northeast, and south of the Netherlands.¹⁸ Of the 3107 persons who participated at the baseline examination in 1992–1993, 2545 (81.9% of total respondents) completed the main interview at the second examination cycle in 1995–1996.^{19,20} At the second cycle, a medical interview was obtained in all participants born before 1931 ($n = 1509$, 87.7% of total respondents). Participants who completed the medical interview and were living in the western region of the Netherlands ($n = 695$) were additionally invited for a clinical examination in a hospital that included a whole-body DXA scan. A total of 449 participants (216 men and 233 women, 64.6% of those invited) agreed to a DXA scan and had complete data on LEP (obtained at the main interview) and muscle strength (obtained at the medical interview) and were included in the statistical analyses. The Ethical Review Board of the Vrije Universiteit Hospital, Amsterdam, approved the study protocol.

Data Collection

During the main interview, trained interviewers from the same area as the participants administered a questionnaire that ascertained basic demographics, health status, physical activity, cognitive functioning, and depressive symptoms and assessed LEP. During the medical interview anthropometric measurements and grip strength were obtained by trained interviewers. Both interviews were obtained at the participants' homes. Leg skeletal muscle mass was assessed during an additional clinical examination in a hospital.

Lower-Extremity Performance

Lower-extremity performance was measured using a timed walking test and a timed chair stand test. To test walking performance, a 3-m walking course was created with a measuring line in the participant's home. Participants were instructed to walk to the other end of the course, to turn around, and to walk back as quickly as possible. They were allowed to use assistive devices if needed. To test the ability to rise from a chair, persons were asked to fold their arms across their chest and to stand up and sit down five times as quickly as possible. The total time to complete each of the two tests was recorded by a trained interviewer.¹⁹ Those completing a test were assigned scores of 1 to 4, corresponding to the quartiles of time needed to complete the test, with the fastest

times scored as 4.¹⁴ Those who could not complete a test (e.g., because they could not walk, were in a wheelchair, were physically not capable, or because the test was not fully completed or was completed with help) were assigned a score of 0. Lower-extremity performance was calculated by summing the walk score and the chair stand score. Values could range from 0 (unable to perform both tests) to 8 (time in fastest quartile for both tests) with excellent reliability (Cronbach's $\alpha = 0.82$).²⁰ Poor LEP was arbitrarily defined as a score of less than 4.

Leg Skeletal Muscle Mass

Leg skeletal muscle mass was assessed by DXA using a whole-body scanner (QDR-2000, Hologic Inc., Waltham MA, USA; fan beam, software version V5.67A). The amount of total body tissue from the scan was positively correlated with measured body weight from a calibrated scale ($r = 0.996$, $P < .001$ for women; $r = 0.995$, $P < .001$ for men). The fat-free and bone-free component of the legs was assumed to represent leg skeletal muscle mass and was calculated as: leg total mass – leg fat mass – ($1.82 \times$ leg bone mineral content).²¹ Because the leg muscles were predominantly involved in the LEP tests used in this study, and because the reproducibility of measuring leg skeletal muscle mass by DXA was better than that of arm skeletal muscle mass (coefficient of variation 1–2% for legs and 3–7% for arms),^{21–23} the statistical analyses were restricted to leg muscle mass. The amount of skeletal muscle mass was positively correlated with body height,¹ so adjustment for body height was necessary to normalize leg muscle mass to height. To avoid spurious correlations when using the ratio of skeletal muscle mass divided by height or height squared, adjustments for body height were made in the statistical analyses.^{24,25}

Muscle Strength

Grip strength was used as an indicator of muscle strength. Grip strength was known to be positively correlated with lower-extremity strength in older persons, with reported correlation coefficients between 0.47 and 0.51.^{6,26} Moreover, grip strength is a reliable (coefficient of variation 3–6% in older persons^{27,28}) and portable muscle strength test that can be administered in a home setting. Grip strength was measured using a grip strength dynamometer (Takei TTK 5001, Takei Scientific Instruments Co. Ltd., Tokyo, Japan). The maximum strength (in kg) out of two attempts of the dominant hand was used.

Potential Confounders

Height was measured to the nearest 0.001 m using a stadiometer. Body mass index (BMI) was calculated as body weight (in kg) divided by height (in m) squared and used as an indicator of body fatness independent of the DXA measurements. The number of self-reported diseases was used as a measure of somatic disease. Participants were asked (yes/no) whether they had or had had any of the following diseases or disease events: chronic obstructive pulmonary disease (asthma, chronic bronchitis, pulmonary emphysema), cardiovascular disease (heart disease, heart attack, arteriosclerosis), stroke, diabetes mellitus, arthritis (rheumatoid arthritis and osteoarthritis), and cancer. To obtain the level of physical activity, participants were asked how often and for how long in the previous 2 weeks they had engaged in exercise.²⁹ The frequency was multiplied by the duration and divided by 2 to

derive the time spent on exercise in minutes per week. For 71.7% of the participants the activity pattern of the past 2 weeks was reported to be representative of the rest of the year. Cognitive functioning was assessed using the Mini-Mental State Examination (MMSE).³⁰ A Dutch version of the Center for Epidemiologic Studies Depression Scale (CES-D), a 20-item self-report scale, was used to measure depressive symptoms.^{31,32}

Statistical Analyses

All analyses were conducted for men and women separately using SAS software (SAS Institute Inc., Cary, NC, USA). The significance of differences in characteristics between men and women and between persons included and those not included in the statistical analyses were compared using Student's *t* tests. Because multiple comparisons were made, the *P*-values of this test were adjusted according to the Bonferroni method.³³ Reported correlations were Pearson's product-moment correlations.

The association of leg muscle mass or grip strength (as independent continuous variables) with LEP (as a dependent variable) was tested using regression analyses. For each of the independent variables, the analyses were adjusted for age and body height to normalize leg muscle mass and grip strength.¹ Second, because body fatness is associated with leg muscle mass, grip strength, and physical function, the analyses were repeated with data adjusted for age, height, and BMI.

The presence of a threshold effect in the association between muscle strength and physical function has been reported in previous studies.^{34,35} Above a certain threshold value, knee extension strength was no longer associated with walking speed^{34,35} and chair stand time.³⁴ To evaluate a threshold in the association with LEP, participants within each sex were categorized by quartile of leg muscle mass or grip strength. Potential differences in LEP between quartiles of leg muscle mass or grip strength were tested using analyses of covariance, adjusting for age and body height, and, in a second model, adjusting for age, height, and BMI.

We repeated the above-mentioned regression analyses adjusting for all potential confounders, including age, body height, BMI, somatic disease, cognitive functioning, depressive symptoms, and physical activity. Possible interactions between leg muscle mass or grip strength and the potential confounders were tested by including product terms in the regression models.

RESULTS

The characteristics of the study sample are shown in Table 1. The prevalence of obesity, defined as a BMI greater than 30 kg/m², was higher in women (34.3%) than in men (11.6%, *P* < .01). The most prevalent somatic diseases were (osteo)arthritis (61% women, 43% men), heart disease (29% women, 38% men) and lung disease (14% women, 18% men). Comparison of the 449 participants included in the statistical analyses with the 246 participants who did not have a DXA scan or had incomplete data revealed that the former had better cognitive function (*P* < .01), better LEP (*P* < .001), and were younger (*P* < .01, women only). The results of the functional performance tests of the lower extremities are shown in Table 2. Poor LEP, defined as an overall score less than 4, was diagnosed in 26.4% of men and 37.3% of women.

After adjustment for age and height, leg muscle mass as a continuous variable was positively associated with LEP in men (regression coefficient 0.178 [95% confidence interval 0.013–0.343], *P* = .035). In women an inverse association was observed (-0.137 [-0.312–0.038], *P* = .13). However, among women, leg muscle mass and BMI were positively associated (*r* = 0.45, *P* < .001). Women with lower leg muscle mass were considerably leaner than those with greater leg muscle mass. Moreover, obesity is known to have a negative impact on physical function.^{36,37} After additional adjustment for BMI, leg muscle mass tended to be positively associated with LEP (0.202 [-0.001–0.405], *P* = .052) in women, an association similar to men. In women, the interaction between BMI and leg muscle mass tended to be statistically significant (*P* = .09). Women with a high BMI tended to have a poorer LEP than expected based on their leg muscle mass. After adjustment for age and height, grip strength as a continuous variable was positively associated with LEP in men (0.107 [0.071–0.144], *P* = .011) and women (0.076 [0.018–0.135], *P* = .0001). This association remained statistically significant after adjusting for age, height, and BMI (*P* = .0001 for men and *P* = .003 for women). No interaction between grip strength and BMI was observed.

Differences in LEP between quartiles of leg muscle mass or between quartiles of grip strength were tested to evaluate a potential threshold in the association. After adjustment for age and height, men in the lowest quartile of leg muscle mass (<13.8 kg) had a poorer LEP (4.3 [SE 0.3]) than those in the

Table 1. Characteristics of Older Men and Women, Longitudinal Aging Study Amsterdam (1995–1996)

	Men (n = 216)		Women (n = 233)	
	Mean (SD)	Interquartile Range	Mean (SD)	Interquartile Range
Age (y)	75.8 (6.4)	70.2–80.8	75.0 (6.4)	69.9–80.4
Height (m)	1.74 (0.06)	1.70–1.78	1.61 (0.06)*	1.57–1.66
Body mass index (kg/m ²)	25.9 (3.4)	23.9–28.4	27.9 (4.8)*	24.5–30.9
Somatic disease	1.2 (1.1)	0–2	1.3 (1.1)	1–2
Cognitive functioning	27.1 (2.4)	26–29	27.4 (2.4)	26–29
Depressive symptoms	6.2 (5.5)	2–9	11.1 (8.0)*	5–15
Physical activity (min/wk)	61 (135)	0–120	42 (80)	0–120
Leg muscle mass (kg)	15.2 (2.0)	13.7–16.7	10.9 (1.7)*	9.7–11.8
Grip strength (kg)	35.3 (8.0)	30–41	21.3 (4.8)*	18–24

**P* < .001 men versus women.

Table 2. Lower-Extremity Performance of Older Men and Women, Longitudinal Aging Study Amsterdam (1995-1996)

	Men (n = 216)		Women (n = 233)	
	n	(%)	n	(%)
Walking test (6 m)				
0 = unable	4	(1.9)	4	(1.7)
1 = slow (≥ 10 s)	52	(24.1)	78	(33.5)
2	60	(27.8)	63	(27.0)
3	39	(18.1)	33	(14.2)
4 = fast (≤ 6 s)	61	(28.2)	55	(23.6)
Chair stands test (5 times)				
0 = unable	11	(5.1)	27	(11.6)
1 = slow (≥ 16 s)	50	(23.1)	53	(22.7)
2	33	(15.3)	45	(19.3)
3	64	(29.6)	51	(21.9)
4 = fast (≤ 11 s)	58	(26.9)	57	(24.5)
Poor lower-extremity performance*	57	(26.4)	87	(37.3)

*Defined as: (walking score + chair stands score) < 4 .

second quartile (5.0 [0.3], $P = .07$), third quartile (5.4 [0.3], $P = .007$), and those in the highest quartile (5.1 [0.3], $P = .07$) (P -value for trend .05, Figure 1). Moreover, LEP was not different between the upper three quartiles of leg muscle mass among men (P -values $> .28$), suggesting a potential threshold in the relationship. Among women, no differences in LEP were observed between quartiles of leg muscle mass (P -value for trend .5, Figure 1). An important difference between the lowest quartile of leg muscle mass and the other quartiles in women was the prevalence of obesity (15.5% in the lowest quartile versus 24.1%, 40.7%, and 56.9% in the other quartiles). After additional adjustment for BMI, women in the lowest quartile of leg muscle mass (< 9.8 kg) had a poorer LEP (4.2 [SE 0.3]) than those in the highest quartile (5.1 [0.3], $P = .03$) (P -value for trend .02). No threshold effect and no interaction between quartiles of leg muscle mass and BMI was observed in women. Low grip strength (< 31 kg for men and < 19 kg for women) was associated with poor LEP in both men (P -value for trend $< .001$) and women (P -value for trend .03, Figure 1). Men in the lowest quartile of grip

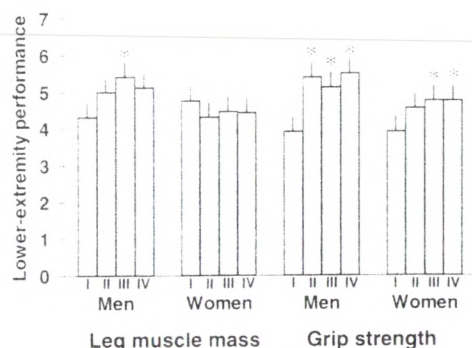


Figure 1. Lower-extremity performance (LEP) (with standard error), adjusted for age and height, according to quartiles of leg muscle mass and grip strength among 449 older men and women of the Longitudinal Aging Study Amsterdam (1995-1996). * $P < .05$ different from lowest quartile (quartile I).

strength had a poorer LEP compared with those in the upper three quartiles. Moreover, no differences in LEP were observed between the upper three quartiles of grip strength in men. These results suggest the presence of a potential threshold in the relationship between grip strength and LEP in men. In women no potential threshold for grip strength was observed.

The relationships of leg muscle mass or grip strength as continuous variables with LEP, after adjustment for all potential confounders, including age, body height, BMI, somatic disease, cognitive functioning, depressive symptoms and physical activity, is shown in Table 3. These results were based on a representation of somatic disease as the total number of somatic diseases. When individual somatic diseases were used in regression models the conclusions of the study did not change. Therefore these results were not reported. In men and women, no association between leg muscle mass and LEP was observed, whereas grip strength remained associated with poorer LEP in men and women. No interaction between leg muscle mass or grip strength and the potential confounders was observed, except for a tendency ($P = .07$) between leg muscle mass and BMI in women. These results were not markedly different when quartiles of leg muscle mass and grip strength were used instead of continuous variables. The P -value for trend of the association between quartiles of leg muscle mass and LEP was .2 for men and .3 for women, whereas the P -value for trend between quartiles of grip strength and LEP was .008 for men and .06 for women.

DISCUSSION

In this study we investigated the association of leg muscle mass and muscle strength with LEP in older men and women. The study had an advantage over previous studies because skeletal muscle mass of the legs was directly assessed using DXA and because timed lower-extremity tests were used as an objective measure of LEP. After adjustment for age and height only, the results showed a positive association between leg muscle mass and LEP in men. In women, after additional adjustment for BMI a similar association was observed. Body mass index was an effect modifier in women, indicating the importance of considering body fatness when investigating the association between muscle mass and physical function in older women.

After adjustment for all potential confounders, including several behavioral parameters and physiological and psychological health parameters, leg muscle mass was not associated with LEP. These analyses suggested that low leg muscle mass per se was not associated with lower-extremity function in older men and women, confirming the results of an earlier study that used self-reported disability.¹⁰ Because the present study was cross-sectional, we cannot conclude that sarcopenia does not influence physical function. Although we observed that low leg muscle mass was not independently associated with poor LEP, loss of muscle mass might have important consequences for physical function. Future studies using prospective data are needed to investigate the association between decreasing skeletal muscle mass and physical function.

As reported in previous studies,⁵⁻⁸ grip strength was positively associated with LEP in both men and women after adjustment for age and height. Although being a direct measure of hand strength, grip strength has frequently been used

Table 3. Linear Regression Model of Lower-Extremity Performance on Leg Muscle Mass or Grip Strength, After Adjusting for All Potential Confounders, Among 449 Older Men and Women of the Longitudinal Aging Study Amsterdam (1995-1996).

	Men			Women		
	β^*	SE	P	β^*	SE	P
Leg muscle mass (kg)	0.151	0.101	.1	0.084	0.102	.4
Age (y)	-0.061	0.021	.004	-0.123	0.022	.0001
Height (m)	-3.493	2.712	.2	-1.815	2.451	.5
Body mass index (kg/m ²)	-0.060	0.045	.2	-0.142	0.032	.0001
Somatic disease	-0.360	0.119	.003	-0.317	0.113	.006
Cognitive functioning	0.039	0.057	.5	-0.007	0.055	.9
Depressive symptoms	-0.087	0.024	.0004	-0.023	0.016	.1
Physical activity (min/wk)	0.001	0.000	.1	0.001	0.000	.02
Grip strength (kg)	0.079	0.019	.0001	0.046	0.028	.1
Age (y)	-0.033	0.021	.1	-0.110	0.022	.0001
Height (m)	-3.663	2.019	.07	-1.182	1.976	.6
Body mass index (kg/m ²)	-0.033	0.034	.3	-0.130	0.025	.0001
Somatic disease	-0.379	0.114	.001	-0.307	0.112	.007
Cognitive functioning	0.016	0.055	.8	-0.014	0.055	.8
Depressive symptoms	-0.083	0.023	.0004	-0.022	0.016	.2
Physical activity (min/wk)	0.000	0.000	.2	0.001	0.001	.03

* β = regression coefficient, SE = standard error, P = P-value.

as an overall measure of body strength because it is a reliable and portable strength test that can be administered in a home setting. Grip strength in older persons was related to arm flexion (reported correlation coefficients between 0.57 and 0.65), knee extension (0.47-0.51), trunk extension (0.33-0.56), and trunk flexion strength (0.37-0.58).^{6,26,38} Because leg strength and trunk strength are necessary for walking and for standing up from and sitting down in a chair, a positive relationship between grip strength and our measure of LEP was expected. After adjustment for all potential confounders, grip strength remained independently associated with LEP in men and tended to be associated with LEP in women. In men, our findings suggested a potential threshold in the association between grip strength and LEP, confirming the results of two previous studies.^{34,35}

A limitation of the study was that the participants included in the statistical analyses using leg muscle mass were those who agreed to come to the hospital for an additional examination that included the DXA scan. It was very likely that frail older persons and those with serious mobility problems were less likely to be included in our study sample. Indeed, those who agreed to the DXA examination had a better LEP compared to the other eligible participants, even after taking age differences into account (data not shown). This selection bias might have weakened the association between leg muscle mass and LEP. Unfortunately, this bias was difficult to prevent because currently no accurate and reproducible body composition methods are available for assessing regional skeletal muscle mass in a home situation.

In conclusion, the results of this cross-sectional study showed that, after adjustment for age and height (and BMI in women), leg skeletal muscle mass was positively associated with LEP. However, after additional adjustment for several behavioral parameters, and physiological and psychological health parameters, this association disappeared, which suggested that low leg skeletal muscle mass per se was not

associated with LEP. Muscle strength remained independently associated with LEP. Future prospective studies are needed to investigate whether loss of muscle mass is associated with physical function in old age.

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